CIRRIPEDES AS PALAEOECOLOGICAL INDICATORS IN THE TE AUTE LITHOFACIES LIMESTONE, NORTH ISLAND, NEW ZEALAND

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The Te Aute lithofacies limestone complex lies on the east coast of New Zealand's North Island. It is comprised of a series of uniform to poorly bedded calcarenites and coquinas of late Neogene age. This limestone complex was deposited off-shore, to the east of the current land mass, and during the late Tertiary-Quaternary period was structurally accreted to the mainland as a series of longitudinal prisms. This paper reviews the current interpretation of the depositional environment, which implies a facies change in the limestone from shallow water in the west, to deeper water in the east. Primarily utilising barnacle palaeobathymetry, it is shown that one of the oldest and most westerly limestones (the mid-Pliocene Titiokura Limestone) was deposited in moderately deep water.

Living barnacles have clearly defined bathymetric ranges and temperature tolerances. When barnacles are abundant in fossil remains, especially of late Cainozoic age, they are often useful palaeoenvironmental indicators. The barnacle fauna of the Titiokura Limestone is characterised by the presence of the deep water balanomorph *Pachylasma*. Species of *Pachylasma* are widely distributed in the living shelf fauna, being found in middle to outer shelf environments, although on very rare occasions specimens may be found living in waters as shallow as 55m. Therefore, on the basis of the abundant and comparatively well preserved plates of *Pachylasma*, it may be inferred that the Titiokura Limestone accumulated in moderately deep, off-shore conditions.

This interpretation is confounded however, by the presence, in the same horizons, of a species of an exclusively intertidal balanomorph, *Epopella*. Whilst it is apparent that the bathymetric ranges of some taxa change through time, all known species of *Epopella* are demonstrably intertidal to uppermost subtidal. They are also characteristic of temperate waters.

Sedimentological observations suggest that the Titiokura limestone is a mixed thanatocoenosis that accumulated in the middle to outer shelf environment. Shallow water elements were introduced as components within submarine avalanches and slurry deposits. Intertidal temperature regimes were probably similar to those currently existing along the New Zealand coastline. ❒ *Te Aute lithofacies limestone, balanomorph cirripedes, Quaternary, palaeobathymetry, palaeotemperatures, submarine avalanches.*

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Cirripedes (barnacles) are very much a Cainozoic phenomenon. Charles Darwin was so taken with their post-Cretaceous abundance that he described Tertiary seas as abounding 'with species of *Balanus* to an extent now quite unparalleled in any quarter of the world' (Darwin, 1854). The Sessilia, or 'acorn' barnacles, are also the ocean's great opportunists, their choice of substrate, both animate and inanimate, being unparalleled amongst the invertebrates. Many sessile barnacles have become sufficiently specialised to be host specific (Buckeridge, 1998). Cirripede palaeoecology is a relatively recent pursuit (Foster & Buckeridge, 1987), with barnacles traditionally interpreted by non-cirripede specialists as shallow water taxa. However improved sampling techniques, in conjunction with deep ocean surveys and recent advances in cirripede phylogeny and biogeography, show a distribution extending well beyond shelf and slope, with taxa recorded from depths in excess of 4000m (Buckeridge, 1997; 1999).

What is of great interest however, is the palaeoecological inferences that we can make regarding balanomorph barnacles through time. The earliest confirmed balanomorphs are known from the Palaeocene of the Chatham Islands (Buckeridge, 1983; 1993; 1996). These include taxa within the genera *Bathylasma* and *Pachylasma* in what, from sedimentological and associated faunal associations, are clearly shallow water sediments (Buckeridge, 1993). No deep water sessilians are known from the early Palaeogene.

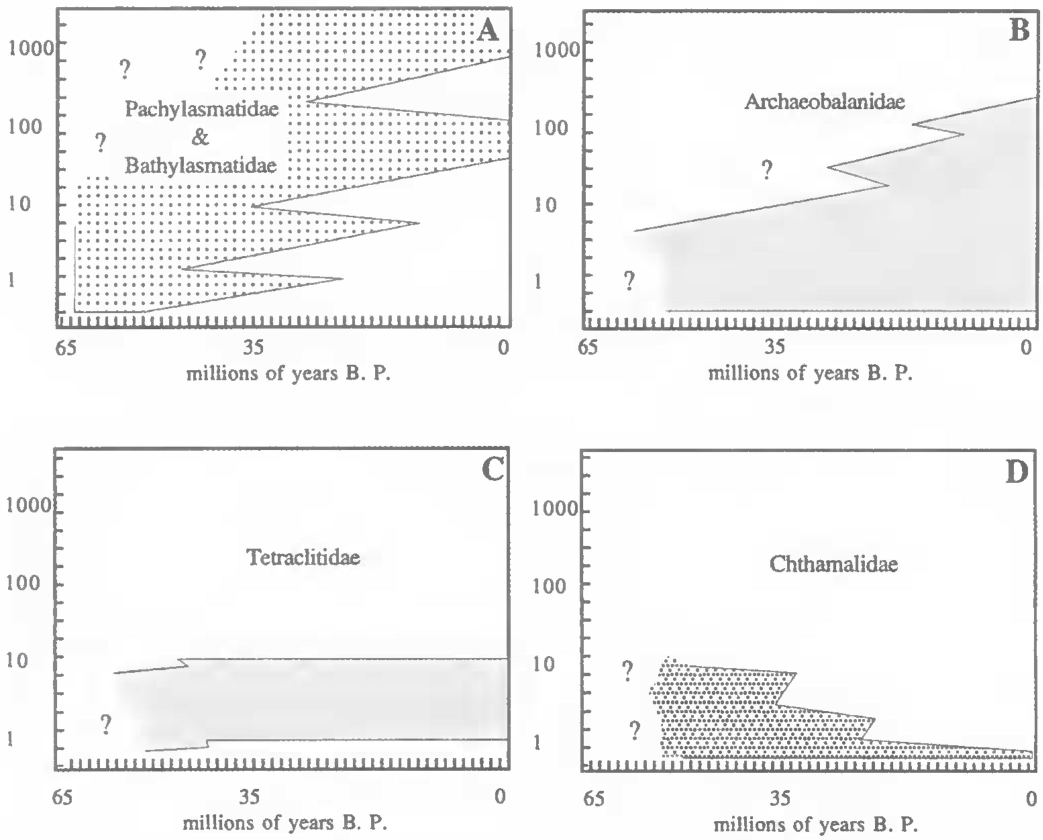

FIG. 1. Schematic representation of preferred environments for 'primitive' balanomorph families in time. Vertical scale: estimated water depth (in metres). A, Pachylasmatidae and Bathylasmatidae; B, Archaeobalanidae; C, Tetraclitidae; D, Chthamalidae. All taxa are interpreted as arising in shallow water environments, with the absence of pachylasmatids and bathylasmatids from shallow water, and chthamalids from all except the uppermost intertidal, being a result of competition, particularly from selected archaeobalanids and the balanids. The balanids become abundant in the Miocene, with many species being characterised by active feeding, high metabolism and early onset of sexual maturity.

The first deeper water balanomorphs are recorded from the earliest Miocene, Cape Rodney Formation in Auckland's Hauraki Gulf (Buckeridge, 1983). There, large numbers of disarticulated plates of *Bathylasma aucklandicum* (Hector, 1888), are found in beds surrounding fossil sea mounts. The inferred depth of deposition for these beds is in excess of 100m. In the Neogene, species of *Bathylasma* and *Pachylasma* are not found in shallow water facies anywhere, with only one living species, *Pachylasma japonica* Hiro, 1933, being found occasionally at depths of less than 80m. The deepest water balanomorph known is the bathylasmatid *Tetrachaelasma tasmanicum* Buckeridge, 1999, which is extremely abundant, both living and as 'sub-fossil', adjacent to deep sea mounts of the South Tasman Rise in depths of 2200-3600m. Preliminary investigations of the balanomorph fauna at, and adjacent to, these sea mounts show distinct zonation of the Sessilia, with the balanomorph species *Bathylasma alearum* (Foster, 1978), and the verrucomorph *Altiverruca gibbosa* (Hoek, 1883) restricted to a shallower zone of 800-2300m. An important characteristic of the deep sea barnacle accumulations is that they have a very low biodiversity. This is certainly the case with the *Tetrachaelasma* beds on the South Tasman Rise; further, the lowest horizons of the Cape Rodney Formation contain abundant *Bathylasma aucklandicum*, but rarely any associated macro-fauna except another deep water barnacle, *Metaverruca recta* (Aurivillius, 1898). Interestingly, stratigraphically higher fossiliferous horizons in the Cape Rodney Formation are supplemented by an influx of shallow water elements, introduced as 'turbid slurries'.

Modern shallow water and intertidal environments in New Zealand and Australia are dominated by chthamalids, tetraclitids and balanids (Fig. 1). The first two groups are known only from shallow water; chthamalids, in particular, are confined to the upper littoral zone, whilst tetraclitids extend to the middle littoral. Providing no evidence of transportation can be demonstrated, this restriction makes both of these families very useful in defining shallow water marine facies.

THE TE AUTE LIMESTONE COMPLEX

The Te Aute lithofacies limestone is a dominant part of the physiography of the central to southern east coast of New Zealand's North Island (Fig. 2). It is comprised of a series of uniform to poorly bedded calcarenites and coquinas of late Neogene age. This limestone complex was deposited off-shore, to the east of the current land mass, and during the late Pliocene-Quaternary was structurally accreted to the mainland as a series of longitudinal prisms.

The term 'Te Aute Limestone' was first used in 1887 by James Hector in his summary of Alexander McKay's geological report for the region (Hector, 1887; MacKay, 1887). At that time, Te Aute was the name of an area characterised by extensive limestone outcrops, south of Hastings in central Hawke's Bay. The term 'Te Aute lithofacies limestone' was coined by Beu (1995) and reflects a greater complexity in the limestones of the region than was perhaps perceived by earlier authors, such as Kingma (1971) and Beu et al. (1980). Beu (1995) established that the Te Aute lithofacies limestone was deposited from Tongaporutuan to early Nukumaruan age (late Miocene to earliest Pleistocene).

Of particular note is the type and nature of the biota comprising the Te Aute lithofacies limestone. Unlike tropical limestones, which are characterised by high levels of lime mud (Campbell et al., 1988), the temperate conditions under which the Te Aute lithofacies limestone was deposited has resulted in a much higher proportion of skeletal material. Of particular interest here is the remarkable dominance of barnacle remains in many horizons. Kamp et al. (1988) recognise the barnacle content to be approximately 13-22% of total rock volume, with the highest percentage characteristic of the Scinde Island Formation (outcropping near Napier). The most impressive 'cirripede dominated lithologies', however, occur in horizons of the Castlepoint Formation, also of Nukumaruan age, which outcrop to the southeast of the Te Aute limestones. In a coarse coquina outcropping at Castlepoint, I have estimated balanomorph content (primarily *Fosterella tubulatus* (Withers, 1924)), to be close to 50%.

PALAEOENVIRONMENT OF THE TE AUTE LITHOFACIES LIMESTONE

Although barnacle limestones are not common, sediment dominated by shells of the barnacles *Notobalanus vestitus* (Darwin, 1854) and *Austromegabalanus decorus decorus* (Darwin, 1854), is currently accumulating at depths of 30m in the Hauraki Gulf, Auckland. Inner to middle shelf deposits, dominated by species of the balanomorph *Fosterella*, were a feature of cooler southern seas in the Pleistocene (Buckeridge, 1983). However, with the extinction of *Fosterella* in the early Holocene, no barnacle species has moved to dominate the shelf environment to the same degree.

Better sampling and recording of the living fauna in recent years has shown that balanomorph barnacles can be significant contributors to sediments forming at depths of 2000m or more (e.g. extensive beds of *Tetrachaelasma* spp. are known from the Southern Ocean off Madagascar, Chile, Cape Horn and Tasmania). In some of these locations, the barnacle shells are found to comprise more than 90% of the calcitic remains (Newman & Ross, 1971; Buckeridge, 1999).

The balanomorph shells preserved in the Te Aute lithofacies limestone are comprised of calcite rather than aragonite (as for many bivalve molluscs). The greater chemical stability of calcite has contributed to the dominance of balanomorphs in many limestone horizons, although this is not the prime factor for their abundance. The environment suited barnacles, especially the now extinct *Fosterella tubulatus* that is so common in Nukumaruan lithologies. Apart from molluscs, the other relatively abundant groups preserved are bryozoans, which possess both aragonitic and calcitic skeletons. According to Kamp et al. (1988), bryozoans never reach the abundance of the barnacles in the Te Aute lithofacies limestones.

PALAEOTEMPERATURES. Barnacles are generally of value in interpreting palaeotemperatures through association, e.g. species of the reef coral symbionts *Hexacreusia* and *Creusia* are characteristic of tropical seas. The

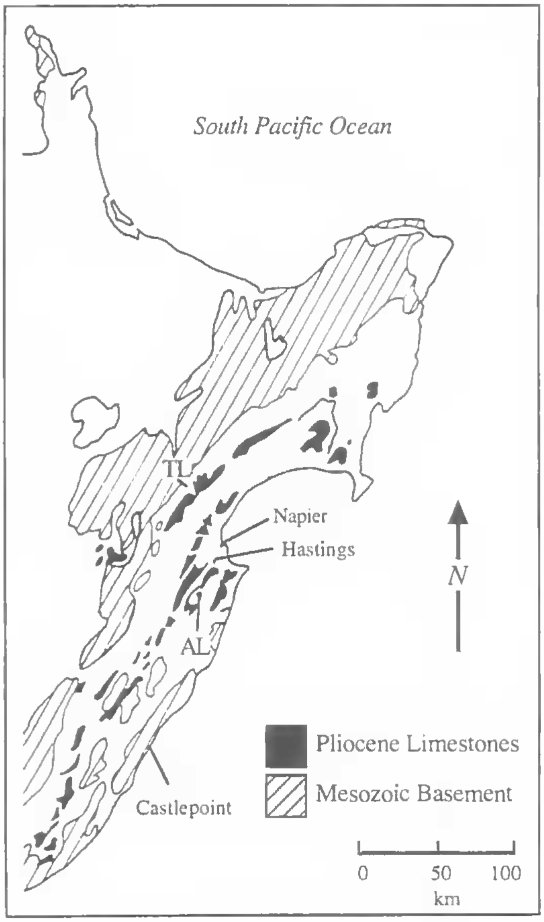

FIG. 2. East coast of New Zealand's North Island, showing localities mentioned in text and distribution of Pliocene 'Te Aute lithofacies limestones' and Mesozoic Basement. TL = summit outcrop of the Titiokura Limestone, AL = Kahuranaki outcrop of the Awatapa Limestone. (Modified from Kamp et al., 1988).

tetraclitid, *Austrobalanus imperator* (Darwin, 1854), is currently known from shallow tropical and subtropical seas off central and northeast Australia. It has also been recorded from the Oligocene of the South Island, a period when sea temperatures were at least as warm as the present. Not surprisingly, it is not found in present New Zealand waters. Species of *Epopella*, another tetraclitid, are found throughout New Zealand and Southern Australia. *Epopella* sp. is also present in the Awapapa Limestone, outcropping on the slopes of Mount Kahuranaki (Fig. 2). Chthamalids are useful indicators of temperature, with the endemic New Zealand species *Chamaesipho brunnea* (Moore, 1944) restricted to warm, temperate intertidal environments. Beu (1995) and Milliman (1974) suggest that the Te Aute lithofacies limestone was deposited in 'shallow subtidal waters'. If this is accepted, the absence of intertidal species (with thick, solid shells like *C. brunnea*), indicates that temperatures were likely to have been cool temperate. This is consistent with the molluscan evidence of Beu (1995).

PALAEOBATHYMETRY. Current interpretation of the depositional environment (Kamp et al., 1988; Beu, 1995), implies a facies change in the limestone deposits, from shallow water in the west, to gradual deepening conditions in an easterly direction. Further to the east again, shallower conditions developed, with the uplift of the East Coast Highlands. It is perceived that a broad NE-SW trending, open seaway, with strong tidal currents (the 'Ruataniwha Strait') characterised the waters between the two land masses.

In Kamp et al. (1988) and Beu (1995) it is proposed that 'large carbonate sand dune-forms' colonised by a barnacle-bivalve-bryozoan assemblage, formed at the margins of the Ruataniwha Strait, and in a moderately high energy 'tidal' environment, migrated to deeper water (i.e. mid-channel). However, Beu (loc. cit.) also refers to Milliman (1974) who states that the porous nature, low resistance to abrasion and fragility of barnacle plates ensures that they 'do not survive transportation from living sites of more than a few tens of metres'. Strong cross bedding, with tangential foreset beds in tabular sets is recognised by Beu (loc. cit) as confirming that the depositional environment was shallow, and dominated by strong tidal currents.

There are some unusual anomalies here, particularly in light of the barnacles present in some mid-Waipipian limestones in the west and central regions. The Titiokura Limestone, outcropping to the northwest, is characterised by a mixed assemblage of barnacles, including *Pachylasma* sp., *Austromegabalanus miodecorus* Buckeridge, 1983, and *Epopella* sp. c.f. *E. plicata* (Gray, 1843). The Awapapa Limestone, which outcrops in the central region south of Hastings, also possesses a mixed barnacle assemblage, including *A. miodecorus*, *Notobalanus vestitus*, *Fosterella tubulatus* and *Epopella* sp., but lacking *Pachylasma*. As discussed earlier, *Pachylasma* comprises exclusively deep water taxa; further, like *Epopella* the shell is non-porous. If the shell is moderately thick, as is the case with large specimens of *Epopella*, it is likely that transportation, albeit with some abrasion, is possible for distances of many hundreds of metres. What is even more important is that *Epopella* is found in the same horizons as *Pachylasma*.

ANALYSIS

A revised sedimentary regime for the New Zealand mid-Pliocene is proposed here. Utilising barnacles as indicators of palaeobathymetry, it is suggested that the western deposits, such as the Titiokura Limestone, represent a depositional environment in water depths of 100m (or more). Shallow water sediments, building up on the margins of the Ruataniwha Strait, were triggered by local overloading, and perhaps micro-seisms, to carry intertidal elements, including *Epopella*, as slurries into the deeper water. The process, although not unlike traditional turbidites, differs primarily in scale, with the distances sediment being transported, and the energy involved in that process, being at least an order of magnitude less than anticipated in 'flysch' deposition. Nonetheless, the mixed thanatocoenosis that the Titiokura Limestone represents is consistent with deposition from a submarine avalanche, which, during the process of its journey, incorporated intertidal (*Epopella*), subtidal (*Austromegabalanus*) and deep water elements (*Pachylasma*).

It is also proposed that the Awapapa Limestone, with a barnacle fauna comprising elements from intertidal (*Epopella*), subtidal (*Austromegabalanus* and *Notobalanus*) and upper-mid shelf (*Fosterella*) environments, formed in a similar manner, but was deposited at depths of only 30-40m. Although there are some similarities, the Awapapa Limestone almost certainly formed in slightly shallower conditions than the extraordinary '*Fosterella* coquinas' of the Castlepoint Formation, outcropping further to the south.

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LITERATURE CITED

BEU, A.G. 1995. Pliocene limestones and their scallops. Institute of Geological and Nuclear Sciences Monograph 10: 1-243.

BEU, A.G., GRANT-TAYLOR, T.L. & de Hornibrook, N.B. 1980. The Te Aute Limestone facies, Poverty Bay to Southern Wairarapa. 1:125,000. New Zealand Geological Survey Miscellaneous Map Series 13 (2 sheets) and Map Notes (36pp.). (Department of Scientific and Industrial Research: Wellington).

BUCKERIDGE, J.S. 1983. The fossil barnacles (Cirripedia: Thoracica) of New Zealand and Australia. New Zealand Geological Survey Paleontological Bulletin 50: 1-151.

1993. Cirripedia and Porifera. In Campbell H.J., et al. (ed.) Cretaceous-Cenozoic geology and biostratigraphy of the Chatham Islands, New Zealand. Institute of Geological and Nuclear Sciences, Monograph 2: 1-240.

1996. Phylogeny and Biogeography of the Primitive Sessilia and a consideration of a Tethyan origin for the group. Crustacean Issues 10: 255-267.

1997. Cirripedia : Thoracica. New ranges and species of *Verrucomorpha* from the Indian and Southwest Pacific Oceans. Mémoires du Muséum national d'Histoire naturelle 176: 125-149.

1998. A new coral inhabiting barnacle, *Chionelasmus crosnieri* sp. nov. (Cirripedia: Balanomorpha) from New Caledonia, Southwest Pacific. Zoosystema 20(2): 167-176.

1999. A new deep sea barnacle, *Tetrachaelasma tasmanicum* sp. nov. (Cirripedia: Balanomorpha) from the South Tasman Rise, South Pacific Ocean. New Zealand Journal of Marine and Freshwater Research 33: 521-531.

CAMPBELL, C.S., KEANE, S.L. & HEAD, P.S. 1988. Non-tropical carbonate deposits on the modern New Zealand shelf. Sedimentary Geology 60: 71-94.

DARWIN, C. 1854. A monograph on the sub-class Cirripedia, with figures of all species. The Balanidae, the Verrucidae. (Ray Society: London).

FOSTER, B.A. & BUCKERIDGE, J.S. 1987. Barnacle Palaeontology. Crustacean Issues 5: 43-62.

HECTOR, J. 1887. Progress report, 1874-76. Geological Survey of New Zealand. Reports of Geological Expeditions during 1874-76. 9: i-xiii.

KAMP, P.J.J., HARMSEN, F.J., NELSON, C.S. & BOYLE, S.F. 1988. Barnacle-dominated limestone with giant cross-beds in a non-tropical, tide swept, Pliocene forearc seaway, Hawke's Bay, New Zealand. Sedimentary Geology 60: 173-195.

KINGMA, J.T. 1971. Geology of the Te Aute Subdivision. New Zealand Geological Survey Bulletin 70.

McKAY, A. 1887. Report on country between Cape Kidnappers and Cape Turnagain. Geological Survey of New Zealand. Reports of Geological Expeditions during 1874-76 9: 43-53.

MILLIMAN, J.D. 1974. Recent sedimentary carbonates. Part 1 - marine carbonates. (Springer-Verlag: Berlin).

NEWMAN, W.A. & ROSS, A. 1971. Antarctic Cirripedia. American Geophysical Union Antarctic Research Series 14: 1-257.